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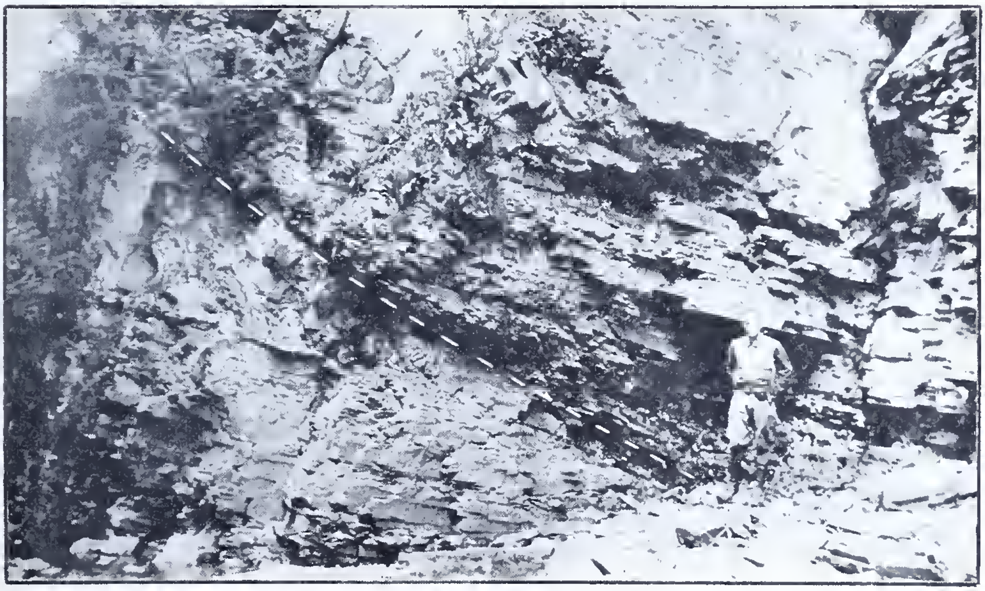
GEOLOGIC STRUCTURE IN THE PLATEAUS REGION OF NORTHERN PENNSYLVANIA AND ITS RELATION TO THE OCCURRENCE OF GAS IN THE ORISKANY SAND

By

S. H. Cathcart



Fault in Chemung. Threefall Run, Ridgebury, Bradford County.

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INTRODUCTORY SUMMARY

This paper summarizes the results of a reconnaissance examination of ructure in the plateaus region of northern Pennsylvania. The area considered tends from northern Clearfield, Elk, and McKean counties on the west to the laware River and includes about 12,000 square miles. Twenty anticlines in this ea have a total length of about 1,000 miles and on these anticlines are about domes that may be considered favorable sites for the accumulation of petroleum.

In 1930 gas in large volume was discovered by wells in Tioga County in Oriskany sand, a "deep" sand of this region. Two promising gas fields have nce been developed and further exploration is in progress.

The manner of the occurrence of gas and oil in the "shallow" sands of stern Pennsylvania is reviewed and the probable occurrence of gas in the iskany sand is discussed.

Attention is called to the fact that faulting has been recognized at per cent of the domes mapped and the effect of faulting at the developed elds is emphasized.

Wells that have been drilled to or below the Oriskany sand in Pennsyl- nia are listed and their location shown on maps attached.

RELATION BETWEEN INTENSITY OF FOLDING AND THE OCCURRENCE OF OIL AND GAS IN PENNSYLVANIA

It is believed that the occurrence of oil and gas in Pennsylvania, in mmercial quantities at least, is confined to the plateau regions of the State. rface indications of oil and gas are known in the region east and south of the legheny Front (Fig. 1), but experience has not demonstrated and it perhaps is t to be expected that oil and gas are present here unless in amounts so small at the product could not return the cost of finding it.

This generalization is based upon our knowledge of the difference in the tensity of the forces that have deformed the rocks of the State. Broadly eaking the intensity of deformation in Pennsylvania decreases from southeast to rthwest. In the extreme southeastern part of the State is found schist, marble, eiss, and other metamorphic rocks that are formed under conditions of extreme essure and heat. Between this belt of metamorphic rocks and the Allegheny Front e rocks, although not metamorphosed, are highly folded, often overturned, and ch faulted. In such environments we do not expect to find petroleum. Any pe- oleum originally there probably has been so dissipated by the heat induced by formation that only traces of it now remain.

West and north of the Allegheny Front is the plateaus region. Here the cks are relatively gently folded, the intensity of folding as a rule diminish- g with distance from the Front. Near the Front are such pronounced folds as estnut Ridge and Laurel Hill that go to make up the Allegheny Mountains. In ese folds dips measure up to 15° or more and amplitude exceeds 2,000 feet; the lds are notable for their continuity and parallelism and for the constancy of eir axial trend. As distance from the Front increases, the amplitude of fold- g diminishes until in western Pennsylvania the rocks are only gently warped. ere dips are measured in feet to the mile, amplitude in tens of feet, and axes re pronouncedly sinuous.

The number of the named anticlines in the plateau region of Pennsylvania xceeds 40. In a large way all of them are irregularities on the limbs of the ppalachian geosyncline. The axis of the geosyncline may be said to coincide oughly with a slightly arcuate line drawn from the southwest corner of the State o the southwest corner of McKean County. The Ninevah syncline marks the axis of he geosyncline in southwest Pennsylvania. East and west of this geaxial line rests of successive anticlines increase in altitude. The geosynclinal axis plunges southwest.

The principal oil and gas belt of the State coincides rather closely with the more gently folded area of the plateau. As the volatile hydrocarbon content of coal is inversely proportional to the intensity of folding to which the coal has been subjected, high volatile coal is synonymous with gentle folding, and low volatile coal with more intensive folding. In a coal country it is convenient, therefore, to express the relative intensity of deformation by isovols or lines that indicate equal volatile matter in coal. Fig. 1 shows the distribution of the fields that are dominantly oil-producing, the fields that are dominantly gas-producing, and isovols. From this map* it is apparent that most of the oil fields of Pennsylvania occur in regions where the coals have 38 per cent or more volatile hydrocarbon content, that is, in areas of the plateau that have been most gently folded; also, that where the volatile hydrocarbon content of the coals is less than 38 per cent, gas rather than oil may be expected to occur. We do not know how low the volatile hydrocarbon content of the coals of an area must be before that area can be condemned as possible gas-producing country. Most of the as yet discovered gas fields of Pennsylvania lie west of the 30 isovol line but fields have been found in Pennsylvania where the volatile content of coal is only 17.5 per cent.

Isovol data must of course be used only in a very general way. It will be noted that in southwest Pennsylvania where coal is present almost everywhere and the isovol lines are drawn on abundant data, the lines are not simple. In Cambria County, for instance, an "island" of 22.5 coal occurs east of the 17.5 isovol. In northern Pennsylvania where coal underlies only a fraction of the surface our data are less complete and our isovol lines correspondingly more simple. If "islands" exist they are not known to us. These "islands" are in effect protected areas in which, due to the presence of a more capable rock for instance, the coal has been protected somewhat from the effect of the deforming forces. What applies to coal is applicable to petroleum and it is readily conceived that within an apparently unfavorable area as judged by incomplete isovol data there may exist an "island" area of increased favorability. An example is seen at Gaines, Tioga County, where a small but commercial oil field was discovered east of the 30 isovol.

In spite of the exceptions we can, however, say with assurance that the chances of finding oil fields decrease rapidly with distance east of the 38 isovol, and for gas fields east of the 30 isovol. Further, that in prospecting for gas in the unproven area of northern Pennsylvania favorability diminishes from northwest to southeast.

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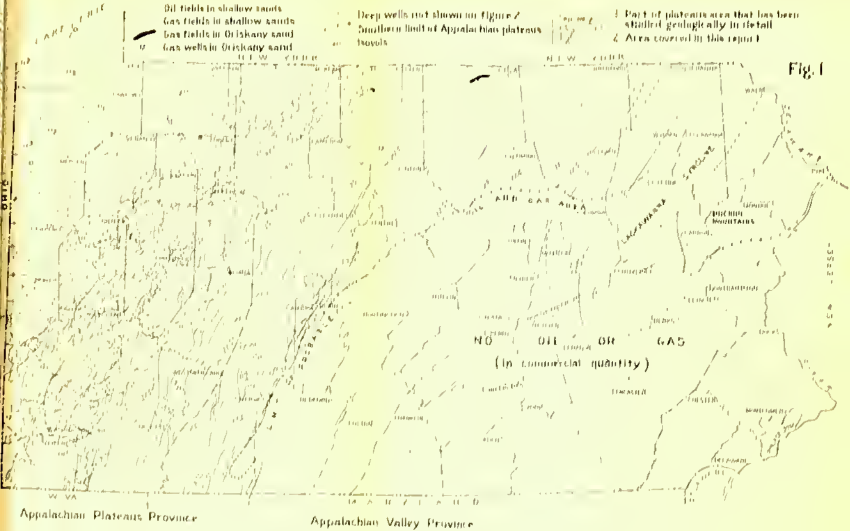
*That a definite relationship exists between the occurrence of petroleum and the volatile hydrocarbon content of coal was first pointed out by David White. The isovol lines were compiled by J. D. Sisler, for the Pennsylvania Geol. Survey from coal analyses made by the U. S. Bureau of Mines.

Footnote: The isovol map we present was prepared by plotting coal analyses values (pure coal basis) geographically without regard for the stratigraphic horizon involved and by contouring the results. Closer accord between volatile hydrocarbon values and the occurrence of oil and gas in any area could be had by reducing the hydrocarbon values to a common datum.

Also the more nearly the horizon contoured coincides with the horizon of the oil-and gas- producing sands, the more useful the result will be. Most of the oil and gas sands of Pennsylvania lie stratigraphically well below most of the coals. In calculating what the hydrocarbon value might be at the deeper sand horizons, account would have to be taken of the unconformity at the base of the Pottsville and of the effect of probable recurring deformation below that unconformity. Considered thus, an isovol line does not represent the intersection of a vertical plane with the map, but of an irregular surface inclined toward the west.

Fig. 1


Oil fields in shallow sands
Gas fields in shallow sands
Gas fields in Oriskany sand
Gas wells in Oriskany sand
Deep wells not shown on figure 2
Southern limit of Appalachian plateaus
Isovols
1 Part of plateaus area that has been studied geologically in detail
2 Area covered in this report
NEW YORK
NEW YORK
OHIO
W VA
MARYLAND
NO OIL OR GAS
(In commercial quantity)
POCONO MOUNTAINS
Appalachian Plateaus Province
Appalachian Valley Province

RELATION OF STRUCTURE TO THE ACCUMULATION OF OIL AND GAS IN WESTERN PENNSYLVANIA*

When the oil and gas fields of western Pennsylvania are plotted on a map** showing structure contours very little relationship between the occurrence of oil and gas and structural highs is apparent. This does not mean that the structural theory of accumulation is not operative, however, but rather that the expected relationship is concealed by stratigraphic and other factors.

In western Pennsylvania 40-odd sandstone horizons are recognized, distributed through more than 6,000 feet of section that includes rocks of Silurian, Devonian, Mississippian, and Pennsylvanian age. (See table, page 4). The number of named oil sands, many supposed equivalents, greatly exceeds 40. In southwestern Pennsylvania the youngest of this series is near the surface; going northeast successively older members come to the surface and in north-central Pennsylvania the oldest members of the group are within easy reach of the drill.

One of the outstanding characteristics of this series of sandstone horizons is the lenticularity of individual sands. This "lenticularity" may be accomplished either by an actual dying out of the sand, by transition into shale, or by the porosity or permeability of the sand diminishing to the point where it ceases to be a capable reservoir. When an oil-or gas-bearing sand quits on the flank of a fold it is obvious that accumulation of its petroleum content must be localized at the upper effective limit of the sand. The structural theory is operative only insofar as the reservoir rock permits it to function and the result is that accumulation occurs in these sands in almost any structural position.

Another factor that modifies the effect of structure on accumulation is the water content of a sand. Some of the sands of our Pennsylvania series are dry, others saturated, and others partly saturated. Oil cannot occur higher on structure than just above the water line. If a sand is continuous over a structural dome, is saturated with water and carries oil and gas, we have the ideal situation for an orthodox occurrence according to the structural theory - gas will be highest on structure, oil below it, and water below the oil. In dry sands oil tends to accumulate at the bottom of the syncline; in partly saturated sands the oil line is at the top of the water line. In a region of small gentle folds and plunging axes the oil content of a partly saturated sand may therefore be distributed throughout a relatively narrow belt that, following a contour, may appear on the plunge of adjacent anticlines and synclines.

It is readily understood why, in the presence of numerous superimposed lenticular sands of variable water content, a usable picture of the relationship of petroleum accumulation to structure cannot be had by plotting productive areas on a structure map. To get an adequate picture, each producing sand needs be considered as a pool in itself, for in any field the factors that govern accumulation may differ for each of the sands present.

In addition to the sand factors that mask the apparent relation of petroleum occurrence and structure, there are structural factors that also are effective.

An ever present influence is the absence of accord between surface and subsurface axes due to asymmetry of the folds. The amount of this discordance tends to increase with depth of the producing horizon below the surface and with the steepness of the limbs of the fold.

Further discordance between surface and subsurface structure results from unconformity. Throughout most of the southern half of the oil and gas fields region wells start above the unconformity that marks the base of the Pottsville (Pennsylvanian) formation and very appreciable differences have been shown

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*For a more detailed discussion, see Pennsylvania Geol. Survey Bull. M-1, The Oil and Gas Fields of Pennsylvania, 1922.

**Oil and Gas Fields Map of Western Pennsylvania, Pennsylvania Geol. Survey, 1932.

Correlation table of principal oil and gas sands and marker horizons of Pennsylvania. *

Systems	Series	Groups	Geologic names of outcropping beds	Driller's names (Correlation below Big Injun and Berea tentative) First name most widely used.	Intervals		
					South-western	Central	Northern
PENNSYLVANIAN	Pittsburgh	Monongahela	Pittsburgh coal	Pittsburgh coal	0		
		Conemaugh	Morgantown sandstone	Murphy sand	140		
			Saltsburg sandstone	Little Dunkard, Cow Run sand	310	700	
			Mahoning sandstone	Big Dunkard, Hurryup sand	515	530	
		Allegheny	Upper Freeport coal	Upper Freeport or Connellsville coal	625	430	
			Freeport sandstone	Upper Gas or Second Cow Run sand	670	390	
			Kittanning sandstone	Middle Gas sand			
			Vanport limestone	Ferriferous limestone		200	
			Clarion sandstone	Lower Gas sand	825	190	
	Pottsville	Beaver River	Homewood sandstone	First Salt sand	915	130	
			Connoquenessing sandstone	Second Salt sand	1000	60	530
			Sharon (Olean) sandstone	Third Salt sand, Maxton sand			430
MISSISSIPPIAN	Chester	Mauch Chunk	Greenbriar limestone	Little lime, Salvation sand	1100		
			Red shale	Pencil cave	1120		
	Meremec	Ste. Genevieve	Loyalhanna limestone	Big Lime, Mountain limestone	1150		
	Waverly (Pocono)	Burgoon	Burgoon sandstone	Big Injun or Mountain sand	1200	0	880
			Shenango sandstone				
		Cuyahoga	Meadville (Patton)	Red shale	1550	300	
			Sharpsville sandstone	Squaw sand	1600		290
			Sunbury (Orangeville)	Papoose sand	1715		
		Berea	Berea (Corry) sandstone	Berea and Murrysville, Butler-thirty-foot, Second Gas.	1775	550	150
DEVONIAN	Upper Devonian	"Catskill"	Cussewago sandstone	Hundred-foot, Fifty-foot, and Gantz First sand of Venango County	1875	750	0
			Riceville shale	Thirty-foot, Nineveh thirty-foot	1980	850	
			Woodcock sandstone	Snee, Blue Monday, Boulder, Hickory	2045	925	140
			Saegertown shale	Gordon stray, Third stray, Campbell Run sand, Second sand Venango County	2080 2150	1040	280
			Miller or Salamanca sandstone	Gordon, Third sand of Venango County	2200	1100	380
			Amity shale	Fourth sand			
			Le Boeuf or Panama sandstone	Fifth, McDonald sand	2270	1200	460
		Chemung	Chadakoin shale & flaggy sandstone	Sixth, Bayard sand	2350	1300	580
				Elizabeth sand	2475	1430	730
				Warren First sand (local)	2710	1580	850
			Girard shale	Warren Second sand (local)	2810	1700	930
				Warren Third sand	2900		1000
			Cuba sandstone (?)	Speechley stray	3000	1900	
				Speechley, Glade	3125	2010	1075
				Tiona, Clarendon	3250	2200	1200
			Northeast shale, etc.	Balltown, Gartland, Cherry Grove sands	3360	2300	1280
				Second Balltown, Chipmunk			
				Sheffield, Cooper (?) sand	3510		1570
			Shumia sandstone	First Bradford sand	3620		
			Westfield shale	Second Bradford sand	3700		
			Leona sandstone	Third Bradford, Deer Lick sand	3800	2700	1715
				Smethport, Kane, Elk groups	3900	2850	
	L. Dev.		Oriskany sandstone	Oriskany	6530	5550	5000
SILURIAN	Lower Silurian	Medina	Tuscarora sandstone	Medina sand, Clinton sand of Ohio (Est.)	8300	6750	6100

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*Pennsylvania Geol. Survey: Contributions to Oil and Gas Geology of Western Pennsylvania, M-19, p. 6, 1933.

to exist between the structure of the rocks above and below this horizon. While no unconformities are recognized between the base of the Pennsylvanian and the base of the Devonian, the burden of proof rests with those who do not advocate the periodic recurrence of crustal disturbance throughout that interval; it is to be expected that no two horizons will show strict structural accordance. In general, lines of folding that already were localized in early Devonian time may have continued to be the loci of successive deformations but with variation. Axes probably shifted somewhat and axial trends as well; axial highs probably migrated considerably.

In view of the factors that may influence accumulation in the principal oil and gas fields of the State, it is not surprising that many operators have adopted the view that geology is useless as an aid to finding oil and gas in Pennsylvania. As a result it probably is no exaggeration to say that geology has played a smaller part in the development of Pennsylvania's oil and gas fields than in the development of any area of comparable importance in the world. Do the facts justify the attitude that has prevailed, or where superficial geology proves to be inapplicable should the answer be more intensive geology? The claimed failure of geology to help in Pennsylvania may have been due to amount and kind of geology applied rather than to the failure of geologic principle. The Pennsylvania fields are old; the "Pennsylvania crude" industry is an outstanding one and there is a substantial industrial demand for natural gas. The problem of the industry today is to recover the large amount of oil that remains in the sands of the proven areas and if possible to find new oil and gas fields. Due perhaps to the factor of oil recovery and the need for new gas fields the use of geologists and petroleum engineers in Pennsylvania is increasing.

PROBABLE RELATION OF GAS IN THE ORISKANY SAND TO STRUCTURE IN NORTHERN PENNSYLVANIA

The apparent absence of accord between accumulation and structure in the principal oil and gas fields and the factors contributing toward that apparent lack of accord have been reviewed to permit a contrast being made between what seems to us to be two very dissimilar situations. This paper has to do primarily with the relation between structure and the occurrence of gas in the Oriskany sand. We do not believe that the irregularities of accumulation that are common to the "shallow" sands of western Pennsylvania will be applicable, to the same extent at least, to accumulation of gas in the Oriskany. We believe that the surface work that is recorded in Fig. 2 is of more value in exploring the Oriskany than similar work would be in exploring the "shallow" sands.

In the first place the objective is gas, not oil. Carbon ratios and experience up to now do not suggest the probability of oil being found. This eliminates the irregularities that result from variable water content of sands.

Further, the Oriskany sandstone probably will prove to be more continuous than most of the "shallow" sands. If so, the job of prospecting the Oriskany will be greatly simplified, for any gas present in the sand will be free to accumulate in structural highs. To know the location of such highs or domes is therefore essential. With one possible exception all the gas discovered in the Oriskany up to now seems to be closely related to structural highs. The possible exception is the Moran well, Potter County, concerning which we do not have conclusive information.

It should be emphasized, however, that the Oriskany sand is not present everywhere. The Oriskany formation, if followed along its outcrop east and south of the plateaus region in Pennsylvania, disappears entirely at some localities and elsewhere the sand is missing and the formation is represented by cherty limestone and shale. In the plateaus region wells have found the sand missing at several localities. More detailed mention is made of this on a later page.

STATUS OF GEOLOGIC STUDIES IN THE PLATEAUS REGION OF PENNSYLVANIA

About half of the area of the plateaus region has been studied geologica ly in detail. Of the detailed area (indicated on Fig. 1) all except a few quadrangles along the New York State line were studied primarily with the object of finding out about coal; in relatively few quadrangles were oil and gas given the consideration necessary to a detailed discussion of their occurrence. However, a a result of careful geologic mapping a contoured structure map is available for each quadrangle in the detailed area. For most quadrangles the datum selected in contouring is a coal that outcrops; for some quadrangles subsurface structure map in which an oil-producing horizon is datum, also are available.

Prior to 1931 the only structure studies that had been made in the area described in this paper were those of the Second Geological Survey of Pennsylvani which functioned during the period of 1874 to 1890. In the Second Survey reports structural axes only were indicated. Upon the discovery of gas in the Oriskany sand in Tioga County in 1930 a need was felt for more information on the anticlin of this region and a total of about 8 months during the summers of 1931-32-33 wer spent by the writer and one or more assistants in tracing structures.

The results are summarized on Fig. 2. Various factors, including time, funds, absence of usable horizon markers, and for about 50 per cent of the area the lack of topographic base maps, dictated the use of the strike and dip method of mapping. The results should therefore be considered as of reconnaissance value although, where exposures permitted, a rather detailed reconnaissance was attempted. Larger scale maps showing the data from which Fig. 2 was prepared will be issued for the separate counties.*

If Figure 2 is compared with the structure maps of the Second Survey very appreciable differences will be noted. In reconciling these differences it should be recalled that when the Second Survey functioned popular interest centered in coal; the relation of the occurrence of petroleum to structure was but vaguely formulated and in consequence anticlines and their domed areas received only passing attention. The coal geologist's interest centered in the synclines in this ar for here it was only in the synclines that coal was preserved from erosion. It is understandable, therefore, that the Second Survey's mapping of the synclines shoul be adequate but of the anticlines indifferent.

The structure of the region north of the detailed area and west of the area covered by Fig. 2 is practically unknown to us. Second Survey studies indicate that in general throughout Erie and Crawford counties the rocks have a dip to the south of 17 to 25 feet to the mile. Terracing has been demonstrated but no closed structures have been worked out. Much of the area is so covered with glacial debris that there are few exposures of stratified rock. Throughout Warren Forest, Venango, and Mercer counties the gently warped surface is believed to prevail. Attempts to expand the Venango County fields westward and northwestward have failed. The productive oil sands rise to outcrop, thin, or die out in a nort west direction and glacial debris obscures structurally favorable sites for prospecting.

The first well was drilled for oil near Titusville in 1859. It is an inconsistent fact that although eastern Venango, southwest Warren and southeast Crawford counties include the oldest productive oil lands in the world the geology of the region has never been carefully studied. Of Pennsylvania's 80,000 producing oil wells** it is estimated that about 26,000 are in Venango County, and 28,000 in the Bradford District.***

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*Prepared: Bulletins 106, Potter County; 107, Tioga County; 109, Cameron County.

**Contributions to Oil and Gas Geology of Western Pennsylvania: Bull. M-19, p. 46, 1933.

***A detailed study of Bradford District has been made by The Pennsylvania Geol. Survey; report in preparation.

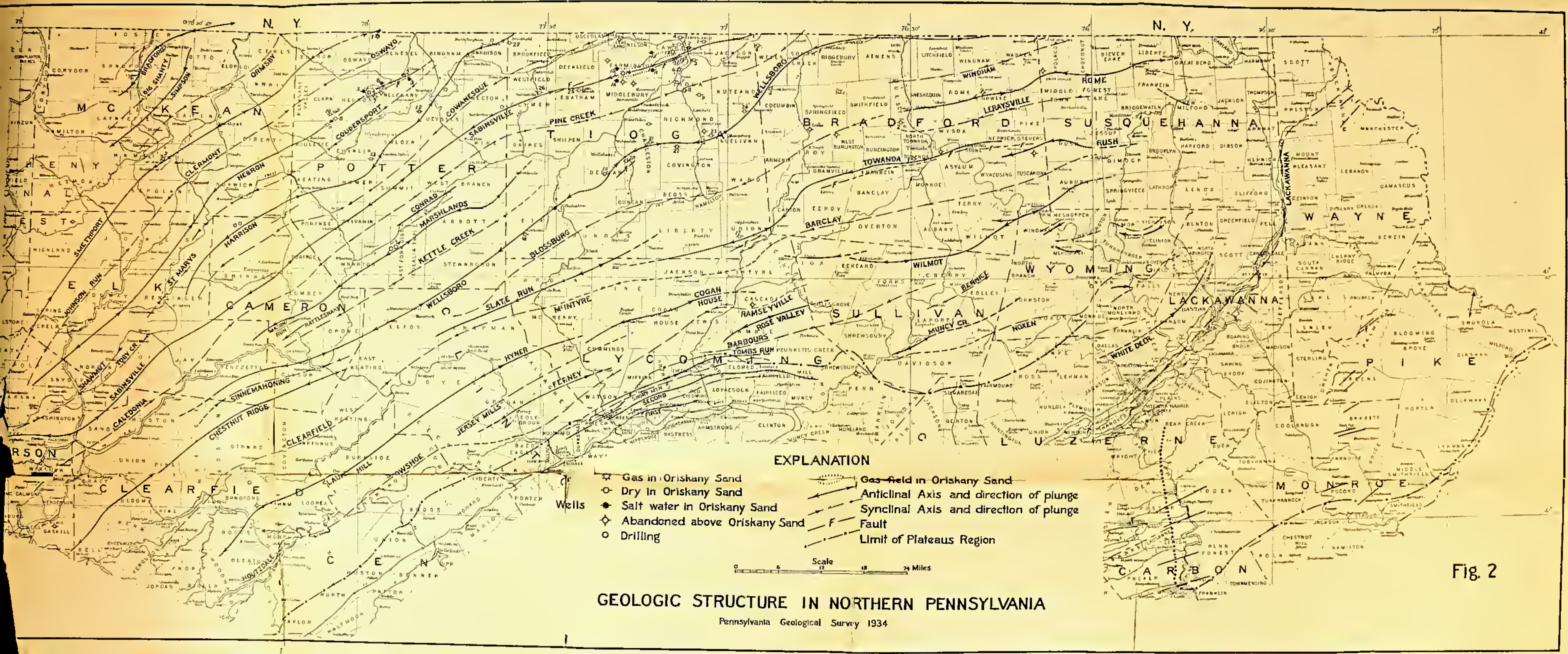

Fig. 2

GEOLOGIC STRUCTURE IN NORTHERN PENNSYLVANIA

Pennsylvania Geological Survey 1934

STRUCTURE

General features. Practically all the area shown on Fig. 2 lies on the eastern limb of the Appalachian geosyncline. The system of folds is arcuate; in the western part of the area structures trend about N.55°E, in the eastern part about N.75°E. The regional plunge of all structures is southwestward. In general the amplitude of folds and the steepness of their limbs diminishes with distance from the Allegheny Front. With few exceptions folds are asymmetric, with slightly steeper south than north limbs.

Earlier published maps* of this area emphasized continuity, parallelism, and simplicity of folds. As shown on Fig. 2 certain of the folds do illustrate these features to a marked degree, but in many instances continuity has suffered at the expense of the en echelon arrangement, simplicity has given way to sinuosity and, as a result, parallelism is a less notable feature of the system.

The longest of the folds (within Pennsylvania) is the Barclay-McIntyre-Clearfield basin which extends from western Susquehanna County to central Clearfield County, a distance of 150 miles. The Sabinsville anticline is 130 miles long in Pennsylvania and extends something like 60 miles into New York. The total length (Pennsylvania and New York) of the Smethport anticline is 175± miles, of the Harrison anticline 160 miles, and of the Wellsboro anticline 170 miles.

A measure of amplitude of folding is afforded by a section through Tioga and Lycoming counties. For the northern half of Tioga County measurements are based upon contours** drawn on the base of the Catskill red beds; for the rest of the section the amplitude is calculated from dip measurements. Maximum values are approximately as follows:

Amplitude between structural axes

	Feet		Feet	
Harrison anticline	1,000	Cowanesque syncline	1,200	Sabinsville anticline
Sabinsville "	2,000	Pine Creek "	1,500	Wellsboro "
Wellsboro "	2,500	Blossburg "	1,900	Slate Run "
Slate Run "	1,000	McIntyre "	1,600	Cogan House "
Cogan House "	1,700	Rameyville "	3,000	Tombs Run "

Cross folding

All the folds appear to belong to one system. An early report indicated the axis of a cross fold trending northwest through Cameron and McKean counties which, in effect, was a line connecting saddles and domes on successive anticlines and synclines. If this practice is followed a number of cross axes can be drawn and no doubt, as detailed information accumulates, the number of such axes made possible would increase. They would not, however, be comparable to the axes of the main system; they would be short and inconstant in orientation. Cross folds in this sense do not necessarily mean that a system of folds having a northwest trend has been superimposed upon a system of folds having a northeast trend, — that two sets of forces that acted in opposed directions and at different times are involved. A certain amount of radial, cross-fold alignment should be expected to occur in any large arcuate system of folds. They perhaps represent no more than adjustment along radial lines.

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*See publications of the Pennsylvania Second Geol. Survey, also Oil and Gas Fields Map of Western Pennsylvania, Pennsylvania Geol. Survey, 1932.

**U.S.G.S. Folios Nos. 92 and 93.

Faulting

Faulting has long been recognized as an important element of structure i the highly folded Appalachian valley province just east of the Allegheny Front bu in general the strongly contrasted gentle folds of the Appalachian plateaus have not been thought of as being faulted structures. More careful examination of the anticlines of northern Pennsylvania and recent deeper drilling in Potter and Tiog counties has shown very conclusively that, in that region at least, faulting not only is of more general occurrence than supposed but that where present its effect upon accumulation of gas in the Oriskany sand is of vital economic importanc

The presence of faulting often is difficult to detect at the surface. This is especially true of structurally high areas, which to the oil and gas geologist are the critical areas, due to the fact that in this region structural hig commonly are underlain by a sedimentary series that includes no good horizon markers but that lithologically shows a monotonous sameness.

Where faulting has been detected at the surface and the details of the effect at the critical horizon has later been shown by drilling, the surface effect has proved to be a mild reflection of actual subsurface conditions. Surface evidence may consist of nothing more than a discordance of dip that is observable at a few scattered localities and yet may prove to be the reflection of a very appreciable subsurface displacement. Two excellent illustrations of this point are afforded by Hebron Field, Potter County* and Tioga Field, Tioga County**.

These meager surface data often may not afford a helpful interpretation of the faulting but their recognition may aid materially in successfully directing exploration. Where faulting is recognized geophysical investigation should precede development work.

On another page we suggest that in this region any surface "indication" has added value because it probably reflects a condition that is amplified at the critical subsurface horizon. This we believe is especially true of fault indication for we suspect that faulting here is very likely to result from vertical rather than from tangential force. That is, that in the plateau region the thrus that resulted in crustal shortening was transmitted by the deeply buried Cambro-Ordovician and older rock (there seem to be no younger strata capable of performing that function) and at the horizon of the present surface the vertical rather than the tangential element of that force was the effective one**.

Localities at which faulting was observed. Surface evidence of faulting was observed at 9 of the 35 domes that were recognized in this area.

At the Farmington dome in Tioga County discordant dips were observed on tl south flank of the fold at two localities, about 1½ miles apart, and interpreted as indicative of faulting. The data were too meager to serve as more than a suggestion. Later drilling disclosed the presence of two fault surfaces inclosing a fault block that is tilted north and shows a maximum displacement of about 500 feet. In proving this about a dozen dry holes were drilled in what had seemed to be favorable structural position. The modest surface indications had economically important subsurface significance.

At Hebron dome, Potter County, steep dips were observed south of the axis at several localities and in view of Tioga Field experience were interpreted as denoting faulting. Subsequent drilling has verified that point. Faulting has bee demonstrated at Hebron dome and in Allegheny Township, 5 miles northeast, but the full significance of it probably has not yet been shown. Fault displacement of 275 feet has been recorded at Hebron dome and of 500 feet in Allegheny Township.

Hebron and Farmington-Lawrence domes are the only ones on which the presence of faulting has been verified by drilling.

In Chatham Township, Tioga County, there is definite evidence of faulting south of the Sabinsville axis. West of this locality is the Sabinsville dome and although the fault was not traced that far it seems probable that the south flank of Sabinsville dome will be found to be faulted. The first observed clue to faulting at this locality was an outcrop of massive, jointed limestone. Bedding was not discernible but the limestone contains large bivalve fossils that "stand on edge" and thus suggest that the attitude of the bed is vertical. Further search revealed discordant dips at two other localities within a distance of a mile and the three localities are in alignment. Here as at Hebron and Farmington domes the surface evidence is meager but suggestive.

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* Bull. 106. **Bull. 107.

At Gardeau in the extreme southeast corner of McKean County a fault surface is exposed in a railroad cut. This fault was pictured by the Second Pennsylvania Geological Survey in their McKean County report*. The break is on the south flank of the Shippen-Norwich dome about 2 miles south of the axis of Harrison anticline. Although faulting was not identified at any other point it may prove to be an important structural element of this dome which is a pronounced high and on which two wells are now being drilled.

Evidence of faulting was observed on the southeast flank of Delmar dome, Tioga County, about 1½ miles from the axis of Wellsboro anticline, in a small creek tributary to Morris Branch from the north approximately at the east line of Delmar Township. The south flank of this dome shows dips of up to 15° and seismograph** observations verify the suggestion that the steep flank may be faulted.

The south flank of Wellsboro anticline is also faulted at Ridgebury dome, Ridgebury Township, Bradford County. On Three Falls Run just south of Ridgebury the fault surface is visible and farther east the presence of faulting is marked by steep dipping beds that crop in road gutters.

It has been reported that there also is evidence of faulting in Little Meadows borough just south of the New York line. Wellsboro anticline is north of this locality and was not traced into New York.

The Towanda anticline appears to be the most profoundly faulted structure in the region. Rocks on the south flank dip 45° to 90° at Union Township dome, Tioga County, and at Towanda dome in Bradford County. Southeast of Wysox, Standing Stone Township, Bradford County, a fault surface is visible in a road cut, and in southeastern Standing Stone Township, and in central Stevens Township, cut banks of creeks give definite evidence of faulting. Faulting may be responsible for the offset in the Towanda-Rush anticlinal axes in Herrick Township.

Importance of the fault consideration in locating wells to test the Oriskany sand

Experience at Hebron and Tioga fields suggests that in allowing for even the most meager of surface indications of faulting, from one hundred to several hundred feet of displacement can be expected at the Oriskany horizon. Effective closure in these, the only two proven fields in the Oriskany sand, ranges from 100 to 300 feet. Dry holes cost between $17,000 and $20,000.

In both Hebron and Tioga fields production has been obtained south of a fault but drilling on the faulted flank has been proven to be very uncertain.

Faulting is not necessarily of the single-plane thrust variety; at Tioga Field block faulting is recognized.

In addition to the effect that it has upon closure, fault movement may also affect the capability of the Oriskany sand to serve as a gas reservoir. The shattered sand near a fault may be recemented by secondary silica (page 20.

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*Second Pennsylvania Geol. Survey, vol. R., p. 34.

**Pennsylvania Geol. Survey., Bull. 107, Fig. 4, February 1934.

It would seem then that while exploratory wells should be located in structurally high position, they should be placed far enough north of a probable fault to avoid a possible recemented effect. We feel that several of the dry exploratory wells drilled in Tioga and Bradford counties may be dry because they met the sand too near the fault.

Surface indications of structure

In a general way the structural highs are reflected at the surface both stratigraphically and physiographically. The degree to which their presence is thus recorded is of course extremely variable and dependent largely upon what part of the rock section is involved at the surface. At best these indications are of rapid reconnaissance value only and their absence need not eliminate highs of moderate intensity. The best examples of surface expression of doming are afforded by the Cogan House, Rose Valley, and Nordmont domes which are described on a later page.

Another criterion of general value is apparent on a glance at Fig. 2; many of the domes are near a sharp bend in an anticlinal axis. Domes so located commonly are well-defined structures which, in this region, means that they show definite northeast closure. Our interpretation is merely that where an axis swings sharply it is good policy to look carefully for evidence of doming in that vicinity.

Pronounced structural height is likely to have been accomplished in part by faulting. The south flanks of strong, well-defined domes should be examined carefully for discordant dips that if present, as previously explained, probably indicate a fault. Faulting was recognized on 25 per cent of the domes mapped and when the limited opportunity for recognizing faults on a reconnaissance survey in this region is considered it seems probable that faulting is much more common tha our mapping suggests.

At many localities the quantity and quality of strike and dip data available may make the recognition of slight northeast closure inconclusive. Likewise the absence of adequate surface expression may make the recognition of faulting open to question. However, comparison of our reconnaissance results at a number of localities with results obtained by more detailed surface geology and with subsurface results would seem to suggest that any geologic feature that is detectabl at the surface by the method we used is of decided subsurface value. That is, th favorability of our results is more likely to be amplified than discounted at the Oriskany horizon.

Appraisal of surface data

The data upon which Fig. 2 is based vary in quantity and in quality from place to place and in the regularity of their distribution. The county maps being issued, of which Fig. 2 is a summary, show strike and dip data and are designed to indicate the weight that should be given our conclusions concerning any locality. The matter of quantity and distribution is of course apparent at a glance and to provide some means of conveying the idea of quality we have classified our strikes and dips as 1st, 2d, 3d, and 4th class, designating each class by an appropriate symbol. In classifying an observation we considered (1) the number of outcrops in the vicinity that were available to substantiate the observation, (2) size of exposure, (3) favorability of exposure to accurate reading, (4) bedding - whether regular or not, and (5) the type of sedimentation represented. A large outcrop of well-bedded marine strata so exposed as to permit ready determination of the direction of maximum dip and the average amount of dip represented by a number of beds throughout an appreciable dip length was called 1st class; a small isolated crop of cross-bedded continental sediments s 4th class, and so on. While the personal element enters into classifying e data, most of the classification was appraised by one person and should erefore be fairly relative throughout the area.

Description of anticlines*

The anticlines of Fig. 2**, named from northwest to southeast, are listed low. Domes that have been recognized are indicated for each anticline and are med from west to east.

Anticline	Dome	Anticline	Dome	Anticline	Dome
ethport	(Spring Creek (Hamlin (Smethport (Shinglehouse	Marshlands	(Wharton (East Fork (Germania	Towanda-Rush	(Union (Towanda (Rush
bron	(Ridgway (Hebron	Rattlesnake		Laurel Hill (Hyner)	Hyner
rrison	(Shippen- (Norwich (Sweden Valley (Ulysses (North Fork	Wellsboro	(Driftwood (Leidy (Letonia (Delmar (Charleston (Richmond (Ridgebury	Cogan House	Cogan House
binsville	(Falls Creek (Emporium (Summit (Sabinsville (Farmington- (Lawrence	Chestnut Ridge	(Gibson- (Grove	Wilmot	(Forks (Wilmot
Conrad (Cross Fork Junction)		Rome	(Orwell (Friendsville	Ferney	Ferney
		Slate Run	Slate Run	Rose Valley	Rose Valley
				Muncy Creek	Nordmont
				Tombs Run	
				Woolrich-Second	
				First	
				White Deer	

Smethport anticline. The Smethport anticline appears to begin just south Clarion River. Its length in Pennsylvania is 72 miles and it continues for 100± les in New York State. In Pennsylvania the fold is broad and flat and throughout st of its length readily usable surface exposures are few and poor. As a result r reconnaissance data serve only to show the fold in a very general way. South-st of the Smethport steepness and amplitude of folding increase with nearness to e Allegheny Front; northwest of the Smethport the structure is essentially that the warped surface. The Smethport seemed to the writer to represent the limit of efulness in the application of the strike and dip method of mapping; structure pping in the area west of the Smethport must be done by more refined practice.

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regional interpretation of the areal geology is given by the new State Geologic Map published in 1932. This can be secured from Division of Documents, Department of Property and Supplies, Harrisburg, for $1.50. (Stamps not accepted.)

tructure of the Bradford quadrangle is taken from a contoured map prepared by C. R. Fettke for the Pennsylvania Geol. Survey. Report in preparation.

As it adjoins the area in which the warped surface prevails, this fold undoubte ly partakes of the characteristics of that type of folding. If contoured it no doubt would show echelon axes where we picture a single axis, and terraces and structural noses where our data permit us to show only simple limbs.

Evidence of four probable areas of doming was observed; in Spring Cree Township, Elk County, in Hamlin Township and east of Smethport, McKean County, and east of Shinglehouse, northwest Potter County. In each instance southwest closure is assured by the regional plunge of the axis and northeast closure is suggested rather than demonstrated. Amount of northeast closure on the Hamlin and Shinglehouse domes may be small, possibly amounting to little more than terracing.

Gas and some oil have been produced from "shallow" sands throughout mos of the length of the Smethport anticline in Pennsylvania and three wells have been drilled on it to the Oriskany sand. One well in Highland Township, Elk County, and one on the Hamlin dome, McKean County, found the Oriskany sand to be absent at those localities. The third well, in Oswayo Township, Potter County, found gas in the Oriskany. This well had an initial volume of 8 million cubic feet at 1950 pounds rock pressure, but flowed much salt water with the gas.

Hebron anticline. The Hebron anticline can be traced from northeast Jefferson County to northern Potter County, a distance of about 90 miles. Its position in Elk and McKean counties is fixed at frequent intervals by fair data, and in Potter County it can be defined with some accuracy. Throughout Elk and McKean counties, however, data are too unequally distributed to permit more than a rough generalization of the structures behavior; like the Smethport anticline it no doubt reflects to a considerable extent the tendencies of the warped surfa

Two areas of doming are recognized, the one in Horton and Ridgway townships, Elk County, the other in Hebron Township, Potter County. The Ridgway dom is quite well defined, our data suggesting that the high is in south Ridgway Township. The high of Hebron* dome extends practically from the east to the wes line of the township. The south limb of this dome is faulted. Just east of Hebron dome the axis again plunges south and within a few miles is lost. It is probable that a dome is present in Allegany and Genesee townships but our data are too meager to define it.

Gas fields in the "shallow" sands occur throughout much of the length of the Hebron anticline and on Hebron dome a field has been developed in the Oriskany sand.

Harrison anticline. The Harrison anticline begins in eastern Elk County, follows a sinuous course for about 65 miles, and leaves the State in northeast Potter County. It continues for perhaps 100 miles in New York State. The characteristics of this fold are well shown by strike and dip data throughout the south half of its length; north of central Potter County data are few or are of poor quality. North flank dip of 3° and 4° are usual and locally 5° and 6° dips are observed; south flank dips of 5° and 6° are usual and locally dips of 7° and 9° are observed.

Well defined domes are developed at the Cameron and McKean County line and in central Potter County. A third dome is recorded in Ulysses Township, Potter County, although our evidence suggests that north closure here is slight and that the structure may not amount to more than terracing. A fourth dome is suggested in Harrison Township by an abundance of data of poor quality. All these domes illustrate the occurrence of structural highs in the vicinity of sharp swings in the trend of the anticlinal axis. The Shippen-Norwich dome is definitely faulted south of the axis, the fault surface being visible in a railroad cut at Gardeau.

The Harrison anticline is east of the main "shallow" oil and gas field belt, and three wells that have been drilled on it to the Oriskany have failed.

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*Bull. 106.

a well in north Brookfield Township, Tioga County, found Oriskany sand but is f structure, another on the Ulysses Township dome found sand but is dry, the ird, located on the Sweden Valley dome, found the Oriskany sand missing. Two lls are drilling at about 4,800 feet on the Shippen-Norwich dome, one in ysses and one in Harrison townships.

Sabinsville anticline. The Sabinsville anticline was traced from central fferson County to the northeast corner of Tioga County, a distance of about 130 les. It continues in New York State for 60 miles or more and is known to extend uthward into northeast Armstrong County. From eastern Elk County to New York ate the characteristics of this fold are well defined by the strike and dip data ailable; farther south data are few and barely serve to identify the structure. Tioga and eastern Potter oounties the fold is exceptionally high; a low saddle developed in central Potter County, but in Cameron County the axis rises again moderate height.

Five domes are recognized, the Falls Creek, Emporium, Summit, Sabinsville, d the Farmington-Lawrence domes. Of these the last named is by far the most ominent, being in fact the most pronounced high observed in this region. The uth limb is faulted. Tioga* gas field is on this structure.

Sabinsville dome is located just west of Farmington-Lawrence dome and its uth flank may also be faulted. One well drilled on this structure is dry in the iskany and a second well has been started. The Emporium dome affords good osure and stratigraphic advantage but has not been drilled. The Summit Township me is quite definite, but it is not large, for within 2 miles along the axis rikes and dips indicate rapid plunge to northeast and southwest, while south ank dips of 4° to 5° are observed a quarter mile south of the axis and on the rth it is but 2 miles or less to the axis of the Cowanesque syncline. Some in- cation of closure was observed northeast of Falls Creek but our data are not nclusive.

Marshlands anticline. This fold extends from eastern Elk to western tter County, a distance of 50 miles. It is a well-defined fold on which domes e developed in Wharton Township, East Fork District, and at Germania, Potter unty. For a distance east of Sterling Run, Cameron County, in a mountainous strict we have no data and it is possible that closure may also occur here.

A small gas field in a "shallow" sand was developed at Germania and two lls on the East Fork dome have found gas in the Oriskany. The Wharton dome is all and has not been tested.

About 2 miles north of the axis in East Fork District there is evidence a small anticline at Conrad. Reversal was observed near Abbott Township line d terracing at Conrad (Hull). The structure may be a small dome or perhaps ly a nose on the flank of the Marshlands anticline. A similar structure, the ttlesnake anticline, is seen on the south flank of the fold in Cameron County. ere is a decided reversal on Sinnemahoning Creek about a mile north of the is of Kettle Creek syncline, but the mountainous area to the east does not af- rd data to define the structure. It does not extend through to First Fork of nnemahoning and it is not known whether a small closed structure or a nose from e Marshlands anticline is represented.

Wellsboro anticline. This anticline was traced from northern Clearfield unty to New York State, a distance of 140 miles, and extends perhaps 30 miles to New York. It is in effect the en echelon equivalent of the Chestnut Ridge ticline, which in Fayette County is en echelon with the Chestnut Ridge of West rginia. These structures together make up one of the greatest lines of defor- tion in the Appalachian Region. It is everywhere a well-defined fold and, ex- pt for short distances in southeast Elk, southeast Potter, and eastern Tioga unties, can be mapped quite satisfactorily in a reconnaissance way.

Domes are developed at Driftwood, Cameron County, Leidy Township, Clinton unty, Elk, Delmar, Charleston, and Richmond townships, Tioga County and Ridgebury Township, Bradford County.

At Driftwood dome the Wellsboro and Chestnut Ridge axes are but 3 miles apart. They are separated by a shallow syncline that is a local feature common to the overlap of the axes. For the Wellsboro axis there is fair evidence of closure on the north and for the Chestnut Ridge axis very definite evidence of both north and south closure. Detailed work probably would show a rather complicated structure here. Neither of these domes has been drilled.

A "shallow" gas field, now practically abandoned, was developed on the north flank of Leidy dome about 1922. The dome appears to center in Leidy Township, to have good closure both east and west and to offer a large drilling are The Oriskany has not been tested at this locality.

At Letonia dome, Elk Township, Tioga County, there is very fair eviden of north closure. South closure is less well demonstrated by our data but as regional plunge is south the data are acceptable. A well drilled to the Oriska on this dome in 1931 is dry.

Delmar dome* is located at a sharp bend in the axis. The south flank the dome shows dips up to 15° and on this flank just south of Wellsboro there is surface evidence of faulting that probably is an important feature of this struc ture. A well drilled to the Oriskany here got a show of gas but probably was n well located on the dome.

A surface contour map** of the Charleston-Richmond Township area shows broad, regular dome on which are two secondary closures. Subsurface* work has shown that at the Oriskany horizon this is a double-crested structure. Charlest dome as indicated here is located on the north subsurface axis. It is a regular feature with good closure structurally higher than Delmar dome but with a very steep south limb that probably is faulted. A well drilled in what seems to be good structural position on this dome is dry in the Oriskany sand.

The Richmond dome seems to have definite closure although we are not in formed about the subsurface. A well drilled to the Oriskany here is dry.

Two wells located south of the surface axis between the Delmar and Richmond domes were dry in the Oriskany.

In eastern Tioga County the Wellsboro axis again swings sharply north. Surface data at this locality are poor but careful search did not reveal to us any closure in Rutland or Wells townships. Two wells to the Oriskany here are dry.

In Ridgebury Township, Bradford County, there is definite evidence of a dome, the south flank of which is visibly faulted. Dips of 1° to 2° for a distance of one or two miles north of the axis suggest a considerable drilling area on this structure which has not been drilled. No evidence of closure was observed east of Ridgebury Township but indications of faulting have been reported in Little Meadows borough, northwest Susquehanna County.

Chestnut Ridge (Driftwood) anticline. Throughout the north half of Clearfield County our data definitely fix the axis of this anticline at only a few widely separated localities. The structure here is a broad-crested gentle fold the axial area of which is covered by massive Pottsville sandstone which yields very few usable strike and dip data. The only dome recognized is the Gibson-Grove Township dome in Cameron County which has been referred to above in connection with the Driftwood dome.

Rome anticline. South of the Wellsboro anticline through Tioga and Bradford counties is the Blossburg syncline. In southwest Tioga County this basi is 7 miles wide, in eastern Tioga County 14 miles, and in central Bradford Count miles. Here, at its greatest width the basin forks to include the Rome anti- ine which begins near Susquehanna River and extends for 40 miles into central squehanna County.

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* See subsurface map of Delmar and Charleston domes, Pennsylvania Geol. Survey, Bull. 107, February 1934.

**U.S.G.S. Folio No. 193.

There are two domes on the Rome anticline, one in Orwell Township, Brad- rd County, the other in the vicinity of Friendsville, Susquehanna County. A ll to test the Oriskany under Orwell dome was started in 1931 but was abandoned fore the sand was reached. A well drilled in Ulster Township is dry in the iskany but the well is off structure. Another in Apolacon Township, Susquehanna unty, was abandoned above the sand.

Slate Run anticline. This structure extends from central Clinton County southern Tioga County, a distance of 36 miles. It is in effect the en echelon uivalent of Towanda anticline and occupies the same relative position in the stem of folds as Chestnut Ridge anticline. The relation shown here between estnut Ridge, Slate Run, and Towanda anticlines is determined by abundant cellent data.

The high point of the axis of this fold falls in eastern Brown Township, coming County. The drilling area of the dome probably would not be large. The iskany has not been tested here.

Towanda-Rush anticline. The Towanda anticline proper extends from north- n Lycoming County to east of Susquehanna River, Bradford County, a distance of out 48 miles, where, according to the interpretation offered here, it is en helon with the Rush anticline which extends about 15 miles into Susquehanna County.

The south limb of the Towanda anticline shows the steepest dips observed xcept locally) in the plateau region. The steep south limb is definitely fault- i, indications of faulting being observed in southeast Tioga County, between Roy and Monroe borough,on Susquehanna River southeast of Wysox, and in eastern tanding Stone Township, and north of Stevensville, Bradford County. At the three ast named localities faulting is visible, elsewhere 90° and steep reverse dips ndicate the probable break. In general dips of 15° or more occur within a mile outh of the axis and increase rapidly to 45° or more; a mile north of the axis e dip is about 5° or 6°. On the highway southeast of Wysox the fault is well xposed in a cliff above the river. Here the fault seems to lie just south of he axis, and as judged by the presence of faults observed on Rummerfield Creek, tanding Stone Township, and Rockwell Creek, Stevens Township, faulting probably as determined the relation that we show as existing between Towanda and Rush nticlines.

Domes occur along these axes in Union Township, Tioga County, southwest f Towanda, Bradford County, and in Rush Township, Susquehanna County. Wells ave been drilled to the Oriskany sand in Union and Towanda townships, and both re dry. Wells were started in Wysox and Stevens townships but neither reached he Oriskany.

Laurel Hill (Hyner) anticline. The Laurel Hill anticline begins in ayette County and extends to western Lycoming County. In Fayette County it is steep-limbed, narrow-crested fold and forms one of the high ridges that go to ake up the Allegheny Mountains. From central Clearfield County, where our apping begins, northeastward the Laurel Hill or Hyner anticline as it is known n Clinton County, is a broad-topped, gentle fold, the position of whose axis is eterminable only in a general way. In the mountainous region of Centre and linton counties there are few usable rock exposures. The only doming determined n this axis is in the vicinity of Hyner, Clinton County.

Cogan House anticline. In western Lycoming County where the Hyner nticline ends the Cogan House anticline begins. The Cogan House is en echelon o the Hyner and extends for about 20 miles into eastern Lycoming County. A omed area coincides roughly with the length of the axis in Cogan House Township.

This is perhaps the most striking structural unit of the area. It is otable in that it illustrates the relation between plateau structure and topography in a manner that makes that relationship easily understood by anyone. The high of the dome is about north of Cogan House and from a vantage point at this locality the entire structure is visible. The high part of the dome is gently rolling farm land underlain by Catskill red shales and sandstones. Encircling this farm land is a cliff of Pocono sandstone that is about 100 feet high and densely wooded. This cliff or rim rock crowds the axis on the steeper south limb and retreats on the gentler north limb; it drops on the horizon to east and west with the pitch of the axis of the fold. The open valley thus developed in a rugged mountain setting is about 7 miles long (E-W) and 2½ miles wide (N-S). Erosion has removed the upper two-thirds of Catskill formation and in consequence all of the Pocono is gone from the valley area. The view of the rim rock is unobstructed by wooded areas that might mark the presence of residua Pocono "bad lands".

The relation of valley lands to anticlines and mountain lands to synclines is general throughout the plateau country but as a rule features are too large to be viewed and appreciated at a glance as they are here.

No wells have tested the Oriskany under this structure.

Wilmot anticline. This fold extends from northeast Lycoming County to western Susquehanna County a distance of about 40 miles. The axis trends east for 20 miles and then in the vicinity of Dushore, Sullivan County, swings rather sharply northeast. Throughout its east trend the fold is rather narrow-crested and steep-limbed. South flank dips range from 10° to 25° and north flank dips 4° or 5° within a mile of the axis. Also the axis is not strictly continuous throughout this distance, showing an offset or en echelon arrangement in Elkland Township. Throughout its northeast course the fold is broad topped and both limbs have gentle dips.

Two domes were recognized, one in Forks Township, Sullivan County, the other in Wilmot Township, Bradford County. An anticlinal nose runs off from the Wilmot dome in a northwest direction and a terrace was noted on the north flank of the fold at Laddsburg, Bradford County. An abundance of good strike and dip data failed to demonstrate closure on the offset axis in Elkland and Fox townships, Sullivan County. No wells have been drilled to the Oriskany on this anticline.

Ferney anticline. The Ferney anticline appears to begin just west of Susquehanna River in Clinton County and extends to just east of Pine Creek, Lycoming County, a distance of about 20 miles. The high point on this anticline lies east of Susquehanna River in a mountainous region that affords little data with which to locate the high point accurately.

Rose Valley anticline. Another short anticline that resembles rather closely the Cogan House anticline is the Rose Valley. It is not so striking as the Cogan House, due largely to the fact that residuals of Pocono sandstone that remain in the low land give rise to timbered areas that interfere with a view of the structure.

The axis can be followed for only about 14 miles. The high of the axis is in northern Gamble Township, Lycoming County, and probably is marked by twin domes. The fold is steep-limbed and narrow-crested. Dips of 10° to 15° were observed within half a mile south of the axis and dips of 4° to 6° within half a mile north of the axis. The south limb may be faulted.

A well was started to test the Oriskany in Cascade Township but has been abandoned above the sand. The well is low on the north flank near the axis of Bernice syncline.

Muncy Creek anticline. This structure is similar to the Cogan House and Rose Valley anticlines but smaller. The axis could be traced for only 7 miles but it seems certain that this fold or an equivalent fold must continue eastward for another 8 or 10 miles through the mountains of eastern Sullivan and southwest Wyoming counties. Usable strike and dip data are few and poor in the

ntain area which is underlain by massive cross-bedded sandstone and no topo-
phic expression of doming could be recognized along the course of the assumed
ension of the axis.

There is a dome on this axis in the vicinity of Nordmont, the high of
dome being south of Nordmont. Muncy Creek follows the axis and in the vicinity
the dome has carved out an ampitheatre-like valley. The drillable area on the
ucture is small, as the width of the valley barely exceeds a mile.

On the road from Muncy Valley to LaPorte high on the mountain at Wright's
re is an excellent view of the valley that coincides with Nordmont dome.

On earlier maps Muncy Creek anticline is shown as continuous with Tombs
anticline. Special effort was made to establish proof when it became appar-
that the two structures are not continuous.

Other anticlines. Early reports include mention of the Tombs Run, "First"
"Second" anticlines and recent drilling in the vicinity of Woolrich predicates
anticline at that locality. All these structures lie just at or south of the
egheny Front and are steep-limbed faulted folds such as characterize the Ap-
achian Valley Province. Dips of 30° to 90° are observed and, where exposures
adequate, faulting and close folds are visible. None of these structures can
considered favorable drilling sites but what appears to be the best location
orded by any of them is on the Tombs Run anticline near the east line of
hony Township.

White Deer anticline. This fold in Lackawanna and Luzerne counties like-
e belongs to the Appalachian Valley rather than to the Plateaus system of
ds. Only its northeast end appears within the limits of the area shown on Fig.
Here it is a gentle fold the axis of which is poorly defined but which appears
plunge regularly to the northeast. Its closeness to the Northern Anthracite
in makes it undesirable for prospecting even though favorable structure were
sent.

Lackawanna syncline

Lackawanna syncline is the dominant structure throughout Wayne, southeast
quehanna, Wyoming, and Lackawanna counties and the parts of Pike, Monroe,
bon, and Luzerne counties that lie north of the escarpment line between Mauch
nk and Matamoras. Minor structural features are recognized within this syn-
nal area but (possibly excepting White Deer anticline) there appear to be no
l-defined anticlines.

The Northern Anthracite fields occur near the axial part of this syn-
ne and extend as far north as southern Susquehanna County. Earlier maps show
Lackawanna axis trending north along the Susquehanna-Wayne County line, trans-
se to the regional trend of the Plateau folds, but the change to conformable
nd in Wayne County, shown on Fig. 2 is supported by ample strike and dip data.

North limb. Eastern Susquehanna and northern Wayne counties are pretty
roughly covered with glacial drift. Natural exposures of rocks are few but
ern road construction affords enough data to indicate, in a general way at
st, what happens as the Appalachian folds approach the Lackawanna syncline.
Rome, Rush, and Wilmot anticlines of western Susquehanna County all have
eper south than north limbs. Their dying out is accomplished by the gentler
th limb gradually becoming a terrace which disappears eastward and permits
steeper south limb to merge with the south dip of the Lackawanna syncline.
southernmost fold dies out first as the syncline plunges south and its in-
ence widens in that direction. All the data obtained in eastern Susquehanna,
thern Wayne, and northern Lackawanna counties indicate a general monoclinal
toward the Lackawanna axis. However, proximity of this area to persistent
ds suggests that in effect it is a warped surface that may be expected to show
or closures. There is suggestion of a reversal of dip just south of New
ford.

The southern part of this area that lies north of and adjacent to the Lackawanna axis, that is, including part of Lackawanna and Luzerne counties a all of Wyoming County, affords fair rock exposures and its structure can be determined in some detail. Along the Allegheny Front where it is a recognizable topographic feature and in line with its extension as far east as western Lackawanna County the dip is north into Bowmans Creek syncline. South of this line the beds rise to the axis of White Deer anticline and then dip steeply toward the Lackawanna axis. North of the Bowmans Creek axis southeasterly dips prevai throughout all of Wyoming County the beds rise to the axis of the Wilmot anticline. The prevailing structure between the Wilmot and Bowmans Creek axes definitely is a warped monoolinal surface. Small closures were recognized in the vicinity of Mehoopany and in Nicholson Township, but it is quite certain that n pronounced fold crosses this area. A small closure also was reoognized south o the Bowmans Creek axis in southeast Eaton Township.

The dip observed throughout this region of monoclinal dip north of the Lackawanna axis commonly ranged from 1° to 3° with occasional dips of 4° to 5°. In Lackawanna County dips of 10° to 30° are observed within 1 to 2 miles of the Lackawanna axis.

South limb. Throughout all the area that lies between the Lackawanna axis and the escarpment line that on Fig. 1 connects Mauch Chunk on Lehigh Rive and Matamoras on Delaware River, the regional dip is northwest toward the Lackawanna axis. Near the escarpment the maximum dips are about 15°, throughout Pike and Monroe counties 5° and 6° dips are common while in Wayne and Lackawann counties dips of 1° to 3° prevail except near the Lackawanna axis in Lackawanna County where dips may exceed 25°. The southeast limit of this unit is a topographic feature comparable in form to the escarpment that marks the Allegheny Front. South of the escarpment are the highly folded rocks of the Appalachian Ridge and Valley province in which the folds trend northeast. On the west, between Mauch Chunk and Wilkes Barre, there is no definite escarpment. Here both the physiographic and structural features of the unit merge with the physiographic and structural features of the Appalachian Ridge and Valley province. The outstanding topographic feature of the area is the Pocono Mountain plateau which centers in northwest Monroe County. This is a broad, flat tableland of about 2,000 feet elevation that is underlain by massive Pocono sandstone.

In Wayne, Lackawanna, and Luzerne counties south of the axis outcrops are not numerous and most of them are of indifferent quality. All the data observed indicate that the regional dip is toward the Lackawanna axis. Details of the structure could not be made out but it is probable that here, as in Wyoming County, we have a gently warped monoclinal surface on which it is fairly certain there are no pronounced closures. The only definite reversal observed is in northern Wayne County just south of the synclinal axis. An igneous dike of diabasic texture was observed on the river road about 2 miles north of Narrowsburg and again just west of Banningville on the road to Beach Lake.

In Pike, Monroe, and Carbon counties about the only usable rock exposur occur east of Pocono Plateau in road cuts. The sandstone that underlies Pocono Plateau yields almost no strike and dip data but it is probable that some minor folds are present here.

West of Lehigh River in the Appalachian Ridge and Valley area is a rath complex system of strong folds that trend about N.55°E. toward Pocono Plateau. That the effect of these folds probably is reflected in the plateau structure is suggested by data available in eastern Monroe and western Pike counties. A traverse north from Stroudsburg to the Wayne County line shows a series of rather uniformly spaced reversals at about 5-mile intervals that almost certainly do not extend as far east as central Pike County. Where determinable these anticlines are rather insignificant features being sharp and narrow-crested and may be purely local irregularities. On the other hand, it is rather to be expected that the strong folds of the region west of Lehigh River die out gradually along their strike and extend into the Pocono region so that what we have mapped may be the last traces of such folds that persist east of the Poconos. Physiographic data, the absence of a well-defined escarpment on the west edge of the plateau region, favor the latter interpretation.

Near Paupack, Pike County, a road-cut exposure shows an abrupt reversal rom 3° N. to 30° S. and may indicate faulting. A small closure was recognized outh of Shohola, Pike County.

Although neither the quality nor the amount of data available for econnaissance use in the Lackawanna synclinal area will permit a definite tatement, it seems quite certain that no pronounced closures are present here. n view of the fact that drilling would be deep and that isovol values are low he area can hardly be recommended as one in which to prospect for oil or gas.

THE ORISKANY SAND

The Oriskany formation is of Lower Devonian age. It outcrops throughout wide area in the Appalachian Ridge and Valley area east of the Allegheny Front ut in the Plateaus region it is known only through having been encountered in ells.

Lithology. In general* the Oriskany formation where it outcrops is a ine- to coarse-grained, friable, light-colored sandstone but in detail its ithology varies considerably from place to place. Locally it may be conglomertic in part and may include shaly, cherty, ferruginous, or calcareous phases. n eastern Pennsylvania outcrops of Oriskany are dominantly sandy to conglomertic; in central and south-central Pennsylvania chert becomes prominent to ominant; in northern Pennsylvania the basal Oriskany tends to be a decidedly alcareous sandstone and the upper part slightly calcareous. In some areas the andstone member is absent and locally the entire formation is missing, due aparently in some instances to erosion and in other instances to hiatus in eposition.

The lithology of the sand in Tioga Field, Tioga County, as indicated by rill cuttings and fragments blown from wells, is reported by Fettke** as follows:

> "This (the sand) consists of a rather tightly cemented, comparatively pure, medium-grained quartz sandstone ranging in color from light gray to light brownish gray. In thin section, under the microscope, fragments blown from the productive portions are made up almost entirely of an interlocking mosaic of quartz grains possessing average diameters in the coarser portions between 0.5 and 1.5 millimeters and in the finer portions between 0.3 and 0.4 millimeters. In thin section the majority of the grains appear to be angular or subangular, but careful examination in many instances reveals this angularity in part at least is due to the secondary crystalline outgrowth of silica from grains that originally were round. Such secondary silica is the chief cementing material. Thin sections of fragments from the upper portion of the sandstone blown from productive wells, as a rule, contain only a very small amount of calcite irregularly distributed among the quartz grains. This is in marked contrast to the lower portion of the sandstone which, in places where it has been penetrated by nonproductive wells, is almost invariably markedly calcareous. The upper portion of the sandstone in nonproductive wells, though not as calcareous as the lower, is usually at least slightly calcareous. Inasmuch as all the productive wells stop in the upper portion, where the gas is encountered, it is not known whether the lower portion in these wells also is calcareous."

The lithology at Hebron Field, Potter County, is essentially the same as t Tioga Field. Fragments show the sand to be fine-grained, dense, vitreous ock not unlike quartzite in appearance.

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*Bull. 107.

*Pennsylvania Geol. Survey, Mim. Bull. 102-B, p. 1, 1931.

Porosity. Cores of the Oriskany have not been taken in this region. Porosities are determined upon pieces of sandstone blown from wells when they are drilled in. The average porosity* of 61 samples from 18 wells in Tioga Field is 8.8 per cent; of a suite of samples from 19 wells in Wayne-Dundee (New York), Tioga, and Hebron fields is 8.97 per cent; and 2 samples from the Nugent well, Hebron Field, show 9.1 and 9.6 per cent. Porosities observed range from about 3 to 12 per cent.

Capacity. The capacity of the sand is illustrated by results at Tioga and Hebron fields. Prior to Feb. 1, 1934 gas had been found in 43 wells in Tioga Field. Initial volumes of wells ranged from 85,000 to 70 million cubic feet in 24 hours and averaged about 15 million cubic feet. Initial rock pressure averaged about 1600 pounds per square inch. In Hebron Field 14 successful wells range in initial volume from 3½ million to 33 million cubic feet and averaged 13 million cubic feet. Initial rock pressure averaged about 2100 pounds.

In these fields no close relation between porosity of the sand from a well and the volume of that well is apparent. Neither perhaps is the maximum volume of wells (70,000,000 cubic feet daily) entirely consistent with the porosities observed. These possible discrepancies may perhaps be explained by the fact that only the tightest part of the sand may be ejected from the wells as fragments and the test therefore may not be representative of the sand as a who Further irregularity in the sand that may explain its unexpected capacity is the presence of minute fissures, many of which are partly sealed by terminated quar crystals that project from the walls. It would seem that the capacity of the reservoir has been augmented by fracturing, incident perhaps to faulting of the structures.

In Tioga Field wells drilled near the fault have found the Oriskany to be very hard and dry, showing neither gas nor water. The sand apparently is incompetent. Absence of pore space here may be due to complete recementation of the sand by silica. Presumably the sand shattered most near the fault surface, and along this shattered zone siliceous solutions found an easy avenue of circulation. Here deposition from solution resulted in complete closing of both fractures and pores. At a distance from this main channel of circulation, fractures and pores commonly are but partly closed, and it is here that we note their presence and the presence of secondary quartz.

From the foregoing it is seen that where the sand is best known in the Plateau region it probably is not in its original condition but has been subjected to secondary alteration. Our limited information suggests that in faulted structures the sand may have been benefited at a distance from the fault but tha near a fault its capacity to hold gas may have been destroyed. Specific knowledge of the sand will not be had until coring has become an accepted practice.

The gas. At Tioga Field the gas commonly occurs within 18 inches of the top of the sand. Not infrequently volumes of several million cubic feet under 1600 pounds rock pressure develop when the sand has been penetrated but a few inches. The best pay occurs within 6 feet of the top of the sand, althoug in a few instances additional gas has been obtained up to 15 feet in the sand. Similar conditions exist at Hebron Field. On analysis the gas shows about 99.5 per cent methane and has a B.t.u. value of 1030.

Salt water. Too little is known about the occurrence of salt water in this sand to permit any general statement. Edge water has been encountered at Tioga and at Hebron fields and salt water occurs with gas in the Moran well in northern Potter County. None of the exploratory wells that are dry show any water. This includes wells drilled in synclinal position in Tioga County.

Distribution and thickness. The location of all the scattered wells drilled to the Oriskany in Pennsylvania for which we have reliable data is shown in Figs. 1 and 2. A summary of the results of these wells and of selected

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*Bull. 107.

mples from Hebron and Tioga fields is given under List of Wells. Briefed
s of all the wells drilled in Hebron and Tioga fields (to Feb. 1, 1934)
d a few selected detailed logs are given in Pennsylvania Geological Survey
lletins 106 and 107.

Exploration up to now has shown the Oriskany to be absent at the fol-
ving localities — the west end of Hebron dome, Potter County, Sweden Valley
ne, Potter County, Hamlin Township dome, McKean County, in northeast Highland
wnship, Elk County, and (?) at Presque Isle, Erie County. Except on Hebron
ne our information rests on the results of a single well. Although the sand
absent on the west end of Hebron dome a field is located on the east end of
e dome and similar relations may exist at Sweden Valley and Hamlin Township
nes.

In Ulster Township, Bradford County, a well reported 10 feet of Orisk-
y. In Tioga County the thickness ranges from 17 to 69 feet and in Tioga Field
erages 45 feet. No well in Hebron Field, Potter County, has definitely drill-
through the sand. One well was completed 12 feet in the sand, at which
pth it was reported as drilling in shale, but there is no assurance that this
presents total thickness. Thirty-one feet of sand is reported in East Fork
strict and 10 feet in Allegany Township, Potter County. In northern McKean
unty and adjacent New York one well found 20 feet and another 18 feet of Orisk-
y. Two wells in Warren County report 10 and 18 feet, one in southeast Jeffer-
n County 30 feet, and one in Forest County 8 feet. In Crawford County, 5, 10,
d 22 feet, in Mercer County 15 feet, and Erie County 5 and 20 feet are recorded.
southwest Pennsylvania a well in Washington County found 10 feet of Oriskany.

DEEP WELLS IN PENNSYLVANIA

County	Map No.	Well Name	Owner	Elev.	Total depth	Formation		Depth Orsk.	S.L. elev. Orsk.	Depth Medina	S.L. elev. Medina	Results in Orsk.	Com- pleted	Remarks
						Started	Finished							
Bradford	1**	Hettick, G.R.	Penn York Gas Co.	1280	5227	Chemung	Oriskany	5163	-3883			Dry	1932	
	2	Kennedy	W. Keefer, Jr.	1445	5530	Catskill		5510	-4065			"	1931	
	3*	Olson, George	James Duff	1865	5690	"	"	5645	-3789			"	"	
	4	Braested, S. G.	Moiserville Oil & Gas	1635	4750	Chemung		4729	-3094				"	
Tioga	1**	Shoemacker, L.	Lycoming N.G. Corp.	1475	7148	"	Vernon sh.	3932	-2458	7900±	-6425	"	"	
	2	Harrison, C.	Leonard	1049	3750			3481	-2432			Show gas	"	
	3	Roe, C.	Weir-Thorn	1406	4249			4148	-2778			Dry	"	
	4	Ryan	Morgan-Hague	1056	4298			4252	-3196			"	"	
	5	Ryder, W.J.	Brad. Lawrence	1224	4068			4005	-2781			"	"	
	6	Carey, Chas.	Wade & Moore	1038	4317			4285	-3247			"	"	
	7	Smith, H.G.	Tallaferro	1040	5308			5231	-4191			"	1932	
	8	West, Wm.	Lester & Miller	1065	5775			5762	-4697			"	"	
	9	Loveless	Taylor-Lynch	1187	6028			6010	-4823			"	1931	
	10	McCullum	Workman et al	1559	4110			4103	-2544			Salt water	1932	
	11	Howe	Lycoming N.G. Corp.	1743	4391			4375	-2632			" "	1931	
	12	Bostwick	J. E. Trainer	1509	4197			4191	-2682			" "	"	
	13	Boom #1	Lycoming N.G. Corp.	1563	3811			3807	-2244			20 Mil.	"	R.P. 1650
	14	Learn #1	East Penn Dev. Co.	1837	4069			4068	-2231			22 Mil.	"	" "
	15	Meaker #1	Penn United	1677	4203			4197	-2520			73 Mil.	"	" 1530
	16	French	Rogers et al	1953	4592			4577	-2624			Salt water	1933	
	17	Butters	Morris Run Coal Co.	1610	5383			5215- 5275	-3605			Dry	1932	
	18*	Weiboldt	Cayuga Gas Co.	1870	6045	Catskill	Helder- berg	5992- 6017	-4122			"	"	
	19**	Wheeler, I. B.	Lycoming N.G. Corp.	1820	5663	Chemung 110' below top	"	5519	-3699			Show gas	"	
	20	County Farm	Wells Corporation	1378	5581			5516	-4138			Dry	"	
	21	Lacey	Penn United Gas Co.	1677	5347			5297- 5341	-3620			"	1933	
	22	Scofield	W. W. Keefer	1445	5548			5501	-4056			"		

Tioga	23	Davey, W. A.	East Penn Dev. Co.	1335	5684			5285	-3950			Dry	1932	
	24	Updegraff	Updegraff, C.E.	1635	5540			5490	-3855			"	"	
	25	Davis, C.A.	Penn United Gas Co.	1707	4723	Chemung	Helderberg	4672	-2965			"	1931	
	26*	Ackley, F. A.	Lycoming N.G. Corp.	1934	5083	"	"	5020	-3086			"	"	
	27**	Bertch, James	Hope Eng. Co.	1840	4921	"	"	4864	-3024			"	"	
Potter	1	Moran, J.	Cunningham et al	2087	4879	Catskill	Oriskany	4875	-2788			8 Mil.	1933	Salt water and gas
	2	Estes, G.	Atwater et al	2170	5199	"	"	5197	-3027			13 Mil.	"	
	3	Gale	Hammondsport O.&G.	2211	5744	"	"	5732	-3521			Salt water	1932	
	4	Wilcox	Sylvania	2140	5118	"	"	5113	-2973			14½ Mil.	1933	R.P. 2030
	5	White, A. J.	Hungiville et al	1985	5195			5188	-3203			Salt water	"	
	6	Co. Comm.	James Duff et al	2259	5405			5403	-3144			" "	1934	
	7	Coyle, E. A.	Rogers, G.H.	2170	5888			5875	-3705			Dry	1933	
	8**	Matteson	Potter Dev. Co.	2130	5561	Catskill		5160	-2980			"	1932	No sand
	9	Sterns	" " "	2026	5247			5140	-3114			"	1933	Thin sand
	10	Gray Chemical	" " "	2176	5488			5394-5420	-3220				"	No sand
	11	Allen	" " "	2217	5356			5201	-2984			"	"	" "
	12	Moe, F.	Penna. Power & Light	2405	5440	"		5316-5326	-2911			"	"	
	13	Franke, L.	Ballis et al	2250	5881	"		5864	-3614			"	"	" "
	14	Emporium Lumb. #1	East Penn Dev. Co.	1934	6311	"		6280	-4346			85 M.	1932	
McKean	1*	Derrick City	Bradford Deep Well Co.	1576	5760	Chemung	Queenston	4135-4155	-2559	5550-5700	-3974	Show oil	1914	
	2*	Haywood Est.	Atlantic Seaboard	1743	5269	Catskill		5182	-3434			Dry	1934	" "
New York State	1*	Quinlan	J. Reed et al	1686	4295	Chemung		4276-4294	-2590			Show oil and gas	1933	Very hard sand
Elk	1*	#3737 (Kane)	United Nat. Gas Co.	1836	7930	Catskill	"	5400	-3564	7080-7245	-5244	No. Orisk.	1928	Med. very hard Dck.-Orisk.4703'
Warren✓	1*	Ulf #1 (Tidioute)	Fidelity Pet. Corp.	1642	5818	Olean±	"	4334-4349	-2693	5591-5782	-3950	Show salt water	"	15 M. 5620' 100M. 5765' Medina
	2	Youngsville	Star Oil Co.	1208±		Chemung	"	?3510-3520	-2302	4810-5035	-3602	Dry	1922	Drillers' log

Forest	1	#134	Collins & Richards	1200	5252		Salina	4527-4535	-3327			Show gas		Drillers' log
Jefferson	1*	Irvin #1	F. C. Deemer	1350	8220	Clarion	"	7235-7265	-5885			Dry	1932	
Erie	1	Presque Isle	Presque Isle N.G.Co.	580	4450	Portage	Trenton	1565	- 985	2365-2600	-1785	"		No. Orisk. Drillers' log
	2	Miles Farm		600±	2650	"	Queenston	1587-1592	- 987	2524-2568	-1924	Water		750M.2550-55' Drillers' log
	3	#381	Penna. Gas Co.	1180±	3735		"	?2560-2580	-1380	3446-3635	-2266	Salt water		Driller's log
Crawford	1*	#3219 (Geo. & L. Eaton)	United Nat. Gas Co.		3565		Salina	3280-3285				Dry		
	2*	#3508 (Naylor well)	" " " "	1170	4400		Queenston	3023-3033	-1853	4212-4383	-3042	Salt water		30M.gas 4318' in Medina
	3	R. C. Jamison #1		1200±	4619		"	3100-3122	-1900	4347-4536	-3147	Salt water show gas		
Mercer	1*	Probst	Clyde Fisher	990	3225		Through Orisk.	3205-3220	-2215			Salt water		
Washington	1	#770 (McDonald or Geary)	Peoples N.G. Co.	1050	7248			6260-6270	-5210			" "		Driller's log
Westmrld.	1*	#1588 (Booth & Flynn #1)	" " " "		6892		Onondaga?							500M. top Onondaga
	2*	#1842 (Booth & Flynn #2)	" " " "	1122	7756		Salina	6840±	-5718			Dry		Incomplete cuttings. Orisk. absent? 300M in Salina

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[*] Informal communication C. R. Fettke.

[**] Fettke, C. R., Bull. Geol. Soc. America, vol. 44, pp. 601-660, 1933.

Remainder of data by courtesy of operators, especially Allegheny Gas Company and Penn United Gas Company.

/ Location of wells in western part of State that could